Energy Efficiency Penalty and Cost of Optimized Air-Cooled Condenser on 515 MW Boiler

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Issue – very high ACC efficiency penalties reported by EPA[1]

- Peak dry-vs-wet closed-cycle penalty at 100% load: 8.4%
- Average penalty at 67% load: 6.9%
- These poor efficiencies used to calculate additional fuel use required to maintain power output;
- Calculations show high additions of air pollution from additional coal burning if once-through units retrofitted with ACC.

1) U.S. EPA Technical Development Document (TDD) for the Proposed Section 316(b) Phase I New Facilities Rule, Chapter 3: *Energy Penalties, Air Emissions, and Cooling Tower Side-Effects*, November, 2001.

Overview

Efficiency and cost of three air-cooled condenser (ACC) designs with initial temperature difference (ITD) of 35 ^{o}F, 40 ^{o}F, and 44 ^{o}F (at 90 ^{o}F design temperature) compared to performance and cost of basecase conventional wet tower for 515 MW Weston Unit 4 supercritical pulverized-coal boiler.

ITD = difference between ambient air temperature and steam condensation temperture in ACC

ACC on coal plants – Wyodak, 1x330 MW, Wyoming, 1977

Matimba, South Africa 6x665 MW

Millmerran, Australia 2x420 MW

from: GEA PCS website

Streeter Unit 7 parallel wet-dry retrofit, Iowa, 37 MW

from: GEA PCS website

Approach

- Steam Pro™ used to model basecase wet tower configuration;
- Agreement between reported basecase heat rate and Steam Pro™ modeled heat rate within 0.2%;
- Heat rate and auxiliary power demand for all cases calculated at 90 ^{o}F, 67 ^{o}F, 45 ^{o}F, and 23 ^{o}F;
- 34-foot diameter and 36-foot diameter ACC cells modeled.

Wet tower design conditions

- Summer 1% condition: 90 ^oF DB, 76 ^oF WB;
- 12 ^oF approach temperature at design condition;
- Average wet tower water use:
  - Evaporation: 4,750,000 gallons/day
  - Blowdown: 475,000 gallons/day

Cooling tower approach temperature: difference between the cooling water temperature leaving the cooling tower (lowest cooling water temperature achieved) and the wet bulb air temperature.

cost increase versus wet basecase

Case	Annual eff. penalty (%)	Peak eff. penalty (%)	Capital cost increase (%)
35 °F ITD	~1.5	2.8	5-6
40 °F ITD	~2	3.6	6-7
44 °F ITD	~3	4.4	7-8

Dramatically lower efficiency penalties than reported by EPA[1]

- EPA reports annual and peak efficiency penalties of 5.9% and 8.4% for ACC on Chicago area coal-fired boiler;
- Performance of non-optimized existing dry-cooled coal plants compared to wet tower-equipped plants assuming conservative (10 ^{o}F approach) design;
- Apples-to-oranges comparison, non-conservative ACC design compared to conservative wet tower.

1) U.S. EPA Technical Development Document (TDD) for the Proposed Section 316(b) Phase I New Facilities Rule, Chapter 3: *Energy Penalties, Air Emissions, and Cooling Tower Side-Effects*, November, 2001.

efficiency penalty – 40 °F ITD case

EPA TDD (Chp. 3) assumes average coal plant capacity is 67% based on national capacity data.

Site temp. range (oF)	Fraction of annual hours [H]	Capacity factor (CF)	CF weighting factor [CF_w]	Mean heat rate penalty [P_m]	Heat rate penalty contribution per temp. range [$H \times CF_w \times P_m$]
67 – 90+	.20	.85	1.4	2.9[a]	0.81
45-67	.34	.60	1.0	2.0	0.68
23-45	.33	.60	1.0	1.6	0.53
< 23	.13	.60	1.0	1.4	0.18
Estimated annual average heat rate penalty for 40 °F ITD case (%)					2.20

a) The mean heat rate penalty between the full load 90 °F operating point (3.6%) and 2/3 load at 67 oF (2.2%) is 2.9%. The full load heat rate penalty at 67 °F is also 2.9%.

Select ACC for no derating of MW output at design conditions

- Rated output is 515 MW;
- Unit designed to fire 3% more fuel than required to achieve rating;
- Peak efficiency penalty of 2.8% for 35 ^{o}F ITD case, meets 515 MW rating at design condition (90 ^{o}F);
- Peak efficiency penalty of 3.6% for 40 ^{o}F ITD case, achieves 512 MW at design condition, may be little economic incentive to go to 35 ^{o}F ITD.

Comparison of auxiliary power demand – small differences, 40 °F ITD case is optimum

Design Condition	Plant Total Auxiliary Power (MW)			
	23 °F, 67% load	45 °F, 67% load	67 °F, 67% load	90 °F, 100% load
conventional wet tower	27.2	27.6	28.3	40.1
44 °F ITD	25.4	26.7	28.3	40.4
40 °F ITD	24.2	25.0	27.2	40.6
35 °F ITD	25.1	26.3	28.0	41.1

Capital cost using EPA wet tower and ACC vendor cost data

Cooling System	Total Project Capital Expenditure - CAPEX ($ millions)	Increase in CAPEX (%)
Douglas Fir conventional wet tower	752[a]	basecase
Plume-abated FRP wet tower	770	2.4
44 °F ITD ACC	791	5.2
40 °F ITD ACC	797	6.0
35 °F ITD ACC	803	6.8

a) Project CAPEX estimated by project applicant.

CAPEX for wet- and dry-cooled options

Cooling System	CAPEX ($ millions)	Cooling system equipment cost ($ millions)	Increase in CAPEX (%)
Least cost wet tower	885[a]	9[b]	basecase
Plume-abated FRP wet tower	894	12	1.0
44 °F ITD ACC	942	28	6.4
40 °F ITD ACC	948	31	7.1
35 °F ITD ACC	954	34.5	7.8

a) Wisconsin labor rates used in calculating CAPEX.

b) Cost includes surface condenser, cooling tower, condenser circulating water pump, and cold water basin.

Conclusions

- Optimized ACC designs have annual and peak efficiency penalties one-half to one-quarter the values reported by EPA;
- There is little difference in auxiliary power demand of optimized ACC designs and the wet tower basecase;
- Specifying an optimized ACC adds 5-8% to project cost relative to conventional wet tower, and 4-6% to project cost relative to a plume-abated wet tower.

Recommendation – expanded analysis needed

- Need rigorous analysis of a range of ACC designs must be compared to a range of wet tower designs;
- For example, this paper looks at three ACC designs compared to a 12 ^{o}F approach wet tower;
- How would these three designs performed compared to a 10 ^{o}F approach tower or a 15 ^{o}F approach tower?
- This information is vital to understanding the "apples-to-apples" heat rate penalty associated with dry cooling in specific cases.